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Development of a Sensor-Based Ecosystem for Measuring Comfort and Activities in a Multi-Resident Context: the Age-SenseAI Project

Sara Casaccia

*Department of Industrial Engineering
and Mathematical Sciences
Università Politecnica delle Marche
Ancona, Italy
s.casaccia@staff.univpm.it*

Riccardo Caponetto

*Department of Engineering
Università degli Studi di Messina
Messina, Italy
riccardo.caponetto@staff.univpm.it*

Laura Burattini

*Department of Information Engineering
Università Politecnica delle Marche
Ancona, Italy
l.burattini@staff.univpm.it*

Ilaria Ciuffreda

*Department of Industrial Engineering
and Mathematical Sciences
Università Politecnica delle Marche
Ancona, Italy
i.ciuffreda@staff.univpm.it*

Andrea Monteriù

*Department of Information Engineering
Università Politecnica delle Marche
Ancona, Italy
a.monteriu@staff.univpm.it*

Luca Marinelli

*Department of Management
Università Politecnica delle Marche
Ancona, Italy
l.marinelli@staff.univpm.it*

Sara Meletani

*Department of Industrial Engineering
and Mathematical Sciences
Università Politecnica delle Marche
Ancona, Italy
melatani.sara@gmail.com*

Ennio Gambi

*Department of Information Engineering
Università Politecnica delle Marche
Ancona, Italy
e.gambi@staff.univpm.it*

Gian Marco Revel

*Department of Industrial Engineering
and Mathematical Sciences
Università Politecnica delle Marche
Ancona, Italy
gm.revel@staff.univpm.it*

Abstract— The aging population is rapidly growing, increasing the demand for innovative solutions to support elderly individuals while minimizing the burden on caregivers. This paper presents the Age-SenseAI project, a novel measurement ecosystem designed to monitor comfort and activities in multi-resident environments. The system integrates a network of non-invasive environmental and physiological sensors, combined with Artificial Intelligence (AI) and data fusion techniques, to assess daily activities, indoor comfort, and potential health risks. A co-design approach involving professionals was adopted to define technical requirements, ensuring compliance and ethical considerations. The proposed sensor network collects real-time data, enabling personalized comfort assessments and detection of behaviour. Two primary use cases were developed: activity recognition in multi-resident contexts and indoor comfort assessment, integrating both objective environmental parameters and subjective user feedback. The architecture leverages cloud-based processing and AI-driven analytics to provide real-time insights and adaptive control mechanisms, enhancing elderly autonomy and safety. Future research will focus on improving personalization, deep learning models, and validating the ecosystem in real-world multi-resident scenarios. The Age-SenseAI project represents a significant step toward scalable, intelligent monitoring solutions for elderly care.

Keywords—*Well-being, Multi-resident, Activity recognition, measurement of comfort, Aging people*

I. INTRODUCTION

In the last decades, the assessment of activities and the measurement of comfort of ageing people has become particularly relevant owing to the growing of aging population. By 2050, the global population of individuals aged 60 and above is projected to surpass 2 billion, outnumbering children for the first time [1]. Consequently, public expenses on long-term care (LTC) have risen steadily

over the past two decades in European countries and it is projected to increase by 70% of Gross Domestic Product (GDP) by 2070, due to population aging. Moreover, most old people prefer to continue living their own homes [2]: this is advantageous for the reduction of the costs for the health care system and to enable older people to remain socially active as they can easily stay in contact with their family and friends. However, home-based care can place significant pressure on both formal and informal caregivers who may feel physically and emotionally overloaded [3]. Thus, it is crucial to search for innovative technologies able to guarantee old people's physical and social well-being and independence and useful to minimize the burden on caregivers responsible for their care technology [4]. In this context, the monitoring of daily activities and the assessment of an appropriate indoor comfort of the old people have gained increasing scientific attention. The incorporation of the quantitative assessment of indoor comfort is essential not only for the occupant but also for the building consumption energy [5]. In fact, poor environmental conditions, such as suboptimal indoor air quality (IAQ), negatively impact occupants' health and productivity while increasing operational costs associated with heating, ventilation, and air conditioning (HVAC) systems [6]. Consequently, there is a growing need for occupant-centered control (OCC) solutions to improve environmental management in living spaces. Thermal comfort varies significantly among individuals due to personal thermal history, activity levels, and physiological characteristics [7]. Precise assessment of factors like activity recognition is crucial for developing personalized thermal comfort models. In this context, Human Activity Recognition (HAR) systems are essential, as they facilitate the identification of individual activities, directly influencing the estimation of metabolic rates [8] [9]. Several European projects have been proposed to monitor elderly comfort by combining environmental factors with activity recognition

techniques. Age-Adapt project seeks to enhance the well-being for older adults and at the same time to minimize energy consumption by assessing how they adapt to various multi-domain indoor environments. This approach enables us to create models and strategies for adaptive comfort for older adults at different health levels [10]. The support to healthy ageing is the main objective of the NESTORE project which aims to develop a personalized coaching system to motivate individuals to prioritize their health using novel Informational and Communicational Technologies (ICT) including wearable and environmental sensors with a decision support system [11]. The HAAL project and RO-SmartAgeing focus on developing advanced assistive technologies to support people affected by dementia at various stages of the disease. The aim is to create intelligent systems based on multiple existing Active and Assisted Living (AAL) technologies, i.e., that are ready for the upscaling, that acts as a lifestyle enhances care efficiency and supports integrated care over time by the various AAL solutions [12], [13]. The GUARDIAN project is dedicated to creating solutions for monitoring and assisting elderly individuals, particularly in home environments. It integrates various technologies, including a social robot, to support seniors and caregiver remotely in remaindering (e.g., medicine and meal) and monitoring actions (activities of daily living) [14]. WEPOP adopts an innovative approach that contributes to enhancing the personalized well-being, considering the influence of human activity on comfort. This approach provides useful information also for thermo-hygrometric control with a view of energy efficiency in living environments [15]. However, the domain of these projects focuses on single-user scenarios, overlooking the complexities of multi-resident environments where distinguishing individual activities is critical [16]. Addressing this gap, the Age-SenseAI project “Sensing and AI Techniques for Aging Well”, cascade call of the PNRR project Age-it, proposes an innovative sensor ecosystem to measure activities and comfort of old people in multi-resident settings. The project leverages a non-invasive sensor network embedded in indoor environments, integrated with a robotic platform, wearable sensors and Artificial Intelligence (AI) algorithms. This methodology aims to overcome key challenges in designing and implementing an ecosystem capable of activity and comfort measurement in multi-resident scenarios, opening the way for advanced solutions in old care. In this work the methodological procedure that leads to cover the innovative aspects of the Age-SenseAI system starting from the user requirements is proposed. The rest of this paper is organized as follows. Section 2 presents the methodology, outlining the co-design approach used to define user requirements and the integration of artificial intelligence (AI) techniques for data processing. Section 3 presents the developed system architecture based on the results of Section 2. Finally, Section 4 concludes the manuscript, summarizing key findings, implications, and future directions for the Age-SenseAI project.

II. MATERIALS AND METHODS

A. Co-design Approach

The first stage of the proposed methodology focuses on a co-design approach that actively involves a team of experts including professors, researchers and experts in technology for elderly people [17]. Participants in the co-design process were selected through a call disseminated via the social

media channels of the Age-It project. These channels were used to promote the questionnaire and reach individuals with a professional interest in aging and technology. As a result, the participants were experts affiliated with universities, research centers, and companies operating in the field of technology for older adults. During this phase, a questionnaire comprising five sections was administered to 20 participants via the Google Forms platform. The first section collected general background information about the participants, including their professional affiliation and role. The second section explored the importance of monitoring the activities of elderly individuals, requesting to understand participants’ views on this aspect. The third section addressed the importance of monitoring factors related to the comfort of elderly individuals, aiming to assess how significant this aspect is for the users. In the fourth section, participants were asked to reflect on a set of predefined issues identified by the project and to prioritize them based on their perceived relevance and urgency. Finally, the last section focused on technical aspects, investigating the requirements and preferences for an ideal use case in which the system is fully operational. This section also investigates the type of user interface. A summary of the questions included in the questionnaire is provided on the Table I.

TABLE I. QUESTIONS PROVIDED DURING THE CO-DESIGN APPROACH

Section	Question	Answer
General information		
Importance in monitoring the activities of the elderly	A. Maintaining a level of physical activity B. Reducing the risk of falls. C. Encouraging activities that stimulate socialization D. Monitoring the AAL.	Rating from 1 to 5
Importance to monitor the comfort of the elderly.	A. Thermal comfort B. Visual comfort C. Acoustic Comfort D. Air quality Comfort	Rating from 1 to 5
Open-ended questions: problems to solve through this project	1. Early identification of aging-related diseases 2. Monitoring vital signs to reduce the risk of illnesses 3. Preventing isolation 4. Helping the elderly manage daily activities 5.Reducing the risk of thermal, visual, acoustic discomfort and air quality issues 6.Reducing stress for family members and healthcare assistants 7.Personalization of care 8.Reducing hospitalization	Priority to the points from 1 to 8
Use case and interface	1. What is the main goal that a caregiver should be able to achieve through the project? 2. Which of these technologies would you include in a home environment to monitor the activity and comfort of multiple people? 3. What biomedical and environmental parameters should be monitored to measure activity levels using technological factors? 4.What additional information should Artificial Intelligence and Data Fusion provide to the sensors? 5. The fundamental aspects to consider when designing a technological system for elderly people and caregivers include: A) user-friendly system. B) Privacy protection. C) Non-invasive sensors. D) Low final system costs Do you think there are other equally important aspects to consider? 6. What type of interface do you think is most suitable for the elderly in this project when they need to provide information about their well-being and comfort? 7. What type of interface do you think is most appropriate for the elderly in this project when they need to receive feedback? 8. What type of interface do you think is most suitable for caregivers who need to visualize the results of data processing with Artificial Intelligence and Data Fusion?	1.Open question 2. A. Social robot B.Wearable sensors C. Sensors installed in the environment 3. Open question 4. Open question 5. Open question 6. A. Dashboard web B. Telegram 7. A. Notification via Telegram B. Alert using robot 8. A. Notification via App B. Notification via Telegram

B. User requirement definition

The user requirements definition in the Age-SenseAI project follows a multi-domain evaluation approach, incorporating insights from professionals in aging technology [15]. Guided by the co-design methodology (Section A), this phase ensures that the system is tailored to real user needs while prioritizing usability and ethical considerations. In particular, key environmental factors influencing well-being were identified, including thermal comfort, visual comfort, acoustic comfort, and air quality. Similarly, activity and physiological parameters monitoring were recognized as essential for assessing physical mobility, social engagement, and cognitive well-being (Fig 1(A)). Additionally, fall detection plays a critical role, utilizing motion sensors and wearable technology to distinguish between normal and abnormal movements, thereby enhancing safety and timely intervention. To ensure usability

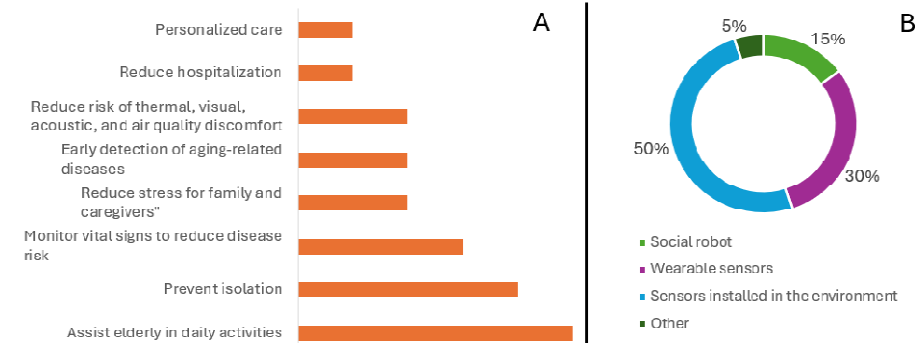


Fig. 1. Overview of the results of the co-design approach based on user survey. A) Importance of the service to be implemented during the project. B) Evaluation of the technologies to be included in the project.

	First Use Case	Second Use Case
Visualization		
Description	Activity measurement in multi-resident contexts	Comfort measurement in multi-resident contexts
Sensors involved	Non wearable sensors (ultrasonic, Passive Infrared, RGB-D camera, Tag, LiDAR), social robot and wearable sensors (i.e. smartwatch, headband)	Environmental sensors for temperature, humidity, CO ₂ levels, particulate matter (PM2.5, PM10), brightness, and noise levels monitoring
End users	Senior, caregivers	Senior, caregivers
Expected outcome	Activity recognition; classification of the intensity of the activity; detection of deviations in behavioural patterns (e.g. fall detection, abnormal activities)	Personal comfort and the general well-being of each inhabitant

Fig. 2. Description of the two use cases identified after the user requirements definition.

and accessibility, in Age-SenseAI project, the adoption of non-invasive sensor placements is emphasized, i.e. robot and environmental sensors (Fig. 1(B)) and intuitive user interfaces, facilitating the interaction and the integration into daily life.

C. Use cases

The transition from user requirements to the definition of use cases in the Age-SenseAI project followed a structured, multi-domain evaluation approach, ensuring that the system effectively meets the real needs of elderly individuals and their caregivers. Through the co-design process, it became evident that monitoring both daily activities and environmental comfort is essential for assessing physical well-being, cognitive engagement, and overall quality of life. These insights led to the formulation of two key use cases (Fig. 2) that integrate non-invasive sensing

technologies and artificial intelligence-driven data analysis to provide valuable feedback for both users and caregivers. The first use case focuses on activity measurement in multi-resident contexts, aiming to monitor the daily behaviours and movement patterns of elderly individuals living in shared environments. This is accomplished through the deployment of non-invasive environmental sensors, including Passive Infrared (PIR), ultrasound, and RGB-D cameras, alongside wearable devices equipped with motion detection sensors, accelerometers, gyroscopes, and physiological measurement tools. While wearable sensors provide an effective way to recognize individuals, a key challenge in this use case is ensuring accurate user identification using non-wearable and privacy-preserving sensors. Given the sensitive nature of personal data, the system must distinguish individuals without relying on intrusive identification methods. To address this, ultrasonic sensors will play a crucial role, leveraging their capability to capture movement patterns and spatial positioning to associate detected activities with specific individuals while maintaining privacy protection. The collected data enables real-time feedback, allowing caregivers to identify potential health anomalies, mobility issues, or deviations in behavioural patterns, facilitating early intervention and personalized assistance. Building upon this foundation, the second use case expands the system’s functionality by incorporating comfort measurement in multi-resident contexts. In addition to tracking physical activity, this use case integrates environmental parameter monitoring, capturing data on temperature, humidity, CO₂ levels, particulate matter (PM_{2.5}, PM₁₀), brightness, and noise levels. The comfort assessment process not only relies on sensor measurements but also incorporates subjective feedback from users through Thermal Sensation Vote (TSV) questionnaires, ensuring a personalized and adaptive evaluation of well-being. An innovative aspect includes the use of Virtual Reality (VR) to simulate different scenario and different activities to study how the comfort perception influences the physiological parameter. Both use cases rely on AI-based data fusion techniques to analyze sensor inputs, detect patterns in activity levels and comfort perception, and generate actionable insights aimed at enhancing the quality of life of elderly individuals. The system is designed to maintain a high level of accuracy, with an uncertainty threshold lower than 10 %, ensuring reliable assessments and meaningful interventions. The integration of AI and

data fusion techniques allow the caregivers to visualize, through a specific interface, the daily reports about elderly’s activity and comfort and to receive timely alerts if a critical event occurs.

III. OUTCOMES

This section presents the sensory ecosystem build to monitor well-being and activities of the elderly.

A. Sensory ecosystem and System Architecture

The Age-SenseAI project includes a comprehensive sensory ecosystem designed to create a multi-layered monitoring infrastructure for elderly care in multi-resident environments. This system integrates environmental, physiological, activity-based, and spatial tracking sensors to facilitate real-time data acquisition and AI-driven analysis, ultimately enhancing the well-being and safety of elderly individuals. The architecture consists of wearable, ambient, and robotic sensing technologies to monitor mobility, activity levels, and behavioural patterns. A network of environmental sensors and home automation systems evaluates thermal comfort, air quality, and overall environmental conditions, while wearable and contactless sensors assess physiological states and cognitive well-being. Immersive technologies further enhance visualization, spatial analysis, and user interaction. At the core of the system, environmental sensors such as RGB-D, Internal Air Quality (IAQ), PIR, and Light Detection and Ranging (LIDAR) continuously monitor the home environment, while physiological sensors—including smartwatches, EEG sensors (i.e. headband), and tags—collect biometric data from users. This data is transmitted via REST API or MQTT to an Amazon Web Service (AWS) cloud infrastructure, which incorporates services like AWS Lambda and a dedicated database for secure data storage and processing. The system can also receive commands and automated actions from the cloud, ensuring personalized safety measures and environmental adjustments. Finally, a caregiver interface provides real-time updates on activities, well-being, and alerts, allowing for effective, proactive remote monitoring and improving overall elderly care management (Fig.3).

IV. CONCLUSION

The Age-SenseAI project presents a novel measurement ecosystem designed to enhance the well-being and activity

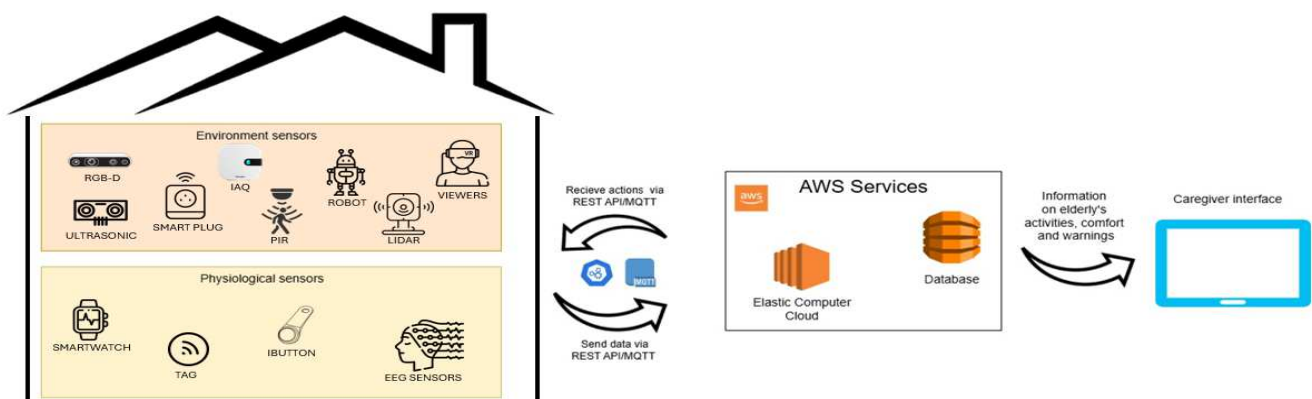


Fig.3. Intelligent Monitoring System Architecture for Elderly Care. The system integrates environmental and physiological sensors to collect data on the elderly person’s condition and the home environment. The data is transmitted via REST API or MQTT to an AWS cloud infrastructure, where it is processed and stored. Caregivers can access a dedicated interface to monitor activities, well-being, and receive alerts.

monitoring of elderly individuals in multi-resident environments. By integrating a network of non-invasive environmental and physiological sensors with artificial intelligence-driven data analysis, the system enables real-time assessment of daily activities, comfort levels, and potential health risks. The proposed approach ensures a user-centered design by incorporating insights from elderly individuals, caregivers, and healthcare professionals, thus addressing both usability and ethical considerations. Through its innovative combination of HAR, environmental monitoring, and artificial intelligence-based data fusion, Age-SenseAI not only enhances the autonomy and safety of elderly individuals but also alleviates the burden on caregivers by providing actionable insights and alerts. The introduction of OCC solutions and adaptive comfort modeling further contributes to optimizing indoor environments for a better quality of life. Future research will focus on expanding the system's capabilities by integrating advanced data fusion techniques, improving personalization through deep learning models, and validating the ecosystem in real/virtual-world multi-resident scenarios.

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